
## Overview of Presentation

- Coordinate Systems
  - Types of coordinate systems currently used.
  - How these coordinate systems relate to a planetary object.
  - What values are used to relate a position within each type.
- Matrix Transformations
  - History of these type of calculations.
  - How to transform between different coordinate systems.
  - The impact to NASA IV&V to have the NASA GOODS package.
- Global Positioning System
  - What the system does for ground based users.
  - How the system is used for spacecraft position determination.
  - How the system may be used in the future.

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## Coordinate Systems

- Earth Based
  - Horizontal, using azimuth and meridian.
  - Equatorial, using declination and hour angle.
  - Ecliptic, using ecliptic latitude and ecliptic longitude.
- Lunar or Planet Based
  - Equatorial, using declination and hour angle.
  - Ecliptic, using ecliptic latitude and ecliptic longitude.
- Solar Based
  - Geocentric Solar Ecliptic System.
  - Geocentric Solar Equatorial System.

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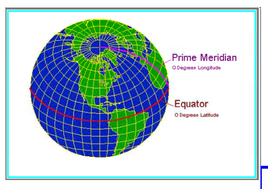
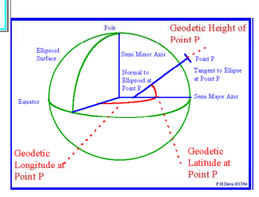
## Views of Coordinates Systems

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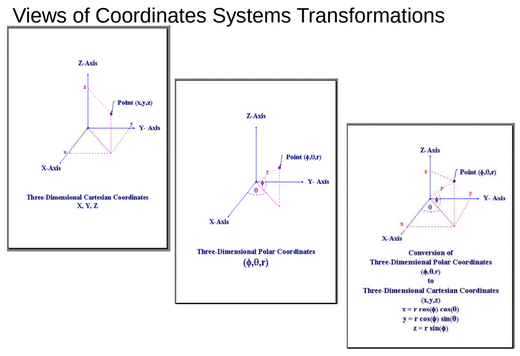
## Views of Coordinates Systems Transformations

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## Coordinate Matrix Transformation Process

- The transformation process requires solving three simultaneous equations through a matrix calculation.
- The transformation of coordinate systems are required between spacecraft (S/C) local coordinates and some outside frame of reference.
- The transformation of coordinate systems are required to point the S/C to a particular object or point of interest.
- The transformation of coordinate systems is used to address an offset of change of position on the S/C of an instrument for field of view.

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## History of this type of Software Application

- At one time hand calculation performed this type of transformations of coordinate systems.
- In the era of high speed computers, large tables of star positions and star charts were generated by the use of transformation algorithms.
- During the space age with flights to the Moon and other planets, which required the use of gravity assistance, these type of transformation took on an important aspect.
- The United States space program took a pre-eminent lead in this area, so much so that help was requested and provided to the Russian space program for their flights to Venus.

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## Background of this type of Software Application

- The Glory project has an instrument that was moved on the S/C platform to improve the field of view after the initial design.
- This required that all coordinates for that instrument would require a transformation to determine the calibration and pointing view.
- NASA IV&V requested a copy of the transformation package used to perform these adjustment based upon Flight Software (FSW) code references.
- The Glory project provided this transformation package so that an analysis could be performed by IV&V to validate that these calculation would be performed correctly.
- Since this software is generally used on the ground to generate and provide ephemeris data to S/C's, it is not generally available to IV&V.
- This has allowed the NASA IV&V facility a unique opportunity to have a software package that is not normally provided and gives us additional insight into FSW performance and applications.

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## The Glory Application to the IV&V analysis efforts

- NASA IV&V now has a reference FSW transformation package.
  - Access to this software package allows a detailed investigation into any FSW system that may use a coordinate transformation to perform the intended function, such as Attitude Correction Systems (ACS).
- NASA IV&V now has an insight into these FSW transformations.
  - The ability to review FSW functional calls to these type of calculations will allow a more detailed understanding for the analyst.
  - The ability to check FSW based upon instrument field of view and position, which may utilize these coordinate transformation.
- File Name : GEODETOplevel.c name changed to GOODS.C by Orbital.
  - Copyright 1998 U.S. Gov't. as represented by the Administrator of NASA.

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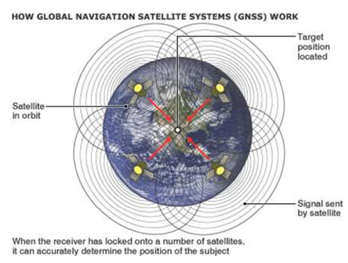
## How Global Positioning System (GPS) Work

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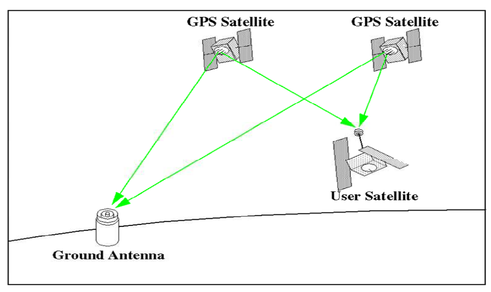
## How GPS Work for Spacecrafts

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## GPS for Spacecraft Navigation

- GPS consists of three components: a space segment of GPS satellites, a control segment that monitors and operates those satellites and a user segment that employs GPS receivers to observe and record transmissions from the satellites and perform position, velocity, attitude and time calculations.
- The space segment is based on three-axis stabilized satellites orbiting in near-circular orbits with a period of half a sidereal day and an inclination of 55 degrees. There are six orbital planes, each with four satellites. This constellation provides global coverage with more than four satellites in view at all times.
- The GPS user segment can determine the position and velocity of a satellite, the time of observations from other tracking or scientific instruments, the attitude of a satellite and relative navigation of two (or more) spacecrafts.

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## GPM & MMS use GPS for Spacecraft Navigation

- The Global Precipitation Measurement Mission (GPM), and the Magnetospheric Multiscale Mission (MMS) utilize the same GPS Navigator (NAV) Flight Software (FSW).
- The NAV FSW consists of two parts. The first part is the CORE GPS System (CGS) Flight Software. The second part is the Goddard Enhanced Onboard Navigation System (GEONS) Flight Software.
- The basic design and operation of the GPS Navigator is based on processing GPS signals. GPS signals are received from antennas located on the spacecraft. GPS signal processing is managed by the Navigator Flight Software.
- The GPS Navigator of the GPM spacecraft (SC) provides orbit determination data to the Attitude Control System on-board and to the ground.

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## The GPS Application to the IV&V analysis efforts

- NASA IV&V now has a reference for FSW using GPS Navigation.
  - The NASA IV&V efforts for MMS and GPM has allowed access to the types of software application which will be used for many future Earth based spacecraft.
  - These application using a GPS system will be applied to other planetary missions, e.g. Moon, Mars, Jupiter, in the future.
- NASA IV&V now has an insight into these GPS application.
  - The utilization of common FSW application between different missions will become more prevalent to reduce costs.
  - Lessons learned during this analysis will be helpful in determining future cost and tasking planning efforts.
  - The risks and areas of concern found during these project common application will help to address future applications using GPS Navigation.

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## The Impact to the IV&V analysis efforts

- To Generate Technical Issues Memorandum's (TIMs).
  - Understanding of Issues with FSW systems that may use a common FSW application to correctly perform the intended function.
  - Understanding of Issues with FSW systems that may use a coordinate transformation to correctly perform the intended function.
  - Generation of Issues or Concerns during the Analysis Phase of IV&V.
- Verification of a Q#2 and Q#3 Questions.
  - Check for Accurate Critical Behaviors.
  - Review of procedures sequence of functional calls to make this type of common FSW applications.
  - Review of the Critical Behaviors and Extensions which may be applicable to these types of common FSW applications.
  - Review of procedures sequence of functional calls to make this type of coordinate transformation calculations.
  - Review of the Critical Behaviors and Extensions which may be applicable to these types of coordinate transformation.

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## The Impact to the IV&V analysis efforts (con't.)

- Validation of the Requirements for Pointing Accuracy.
  - E.g. Instrument Calibration requirements.
  - E.g. Attitude Correction Systems (ACS).
  - E.g. Science Data Collection Accuracy requirements.
- Validation of the Requirements for Positional Accuracy.
  - E.g. Instrument Calibration requirements.
  - E.g. Attitude Correction Systems (ACS).
  - E.g. Science Data Collection Accuracy requirements.

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## Conclusions

- The transformation understand obtained from the Glory application package gives NASA IV&V a detailed insight and understanding into the complex working of celestial navigation.
- The GPS Navigation utilized on the GPM and MMS projects provides insight into future mission shared application FSW and into future missions utilizing GPS techniques.
- The lessons learned and risks from these projects will be helpful to plan and scope future projects with similar applications.
- As the projects become more efficient using shared FSW applications, the analysis by NASA IV&V must become more efficient to provide the same high standards of performance and value to our customers.

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